THE METEOROLOGICAL MAGAZINE

HER MAJESTY'S STATIONERY OFFICE

March 1985

Met.O.967 No. 1352 Vol. 114

METEOROLOGICAL OFFICE Met.O.967

THE METEOROLOGICAL MAGAZINE

No. 1352, March 1985, Vol. 114

The Meteorological Magazine: Editorial Board

It has been decided to set up an Editorial Board for the *Meteorological Magazine*. Members of the Editorial Board will advise the Editor on the content and presentation of articles and encourage the production of scientific papers and other material suitable for publication.

The Board has reached some recommendations on the content of the *Meteorological Magazine*. These may be summarized as follows:

(1) The Editor should continue to seek the submission of articles which describe the results of research in applied meteorology or the development of forecasting techniques. Such articles might be obtained from any source.

(2) Authors should be encouraged to submit papers that are more relaxed and conversational in style than hitherto.

(3) There is a need for review articles which provide up-to-date accounts of different research topics, new operational techniques and procedures, and early informal descriptions of promising new lines of research.

(4) Major research work, the results of which merit publication internationally but is of interest to meteorologists in different specializations, could be made the subject of a simplified article for inclusion in the *Meteorological Magazine*.

(5) Staff at Meteorological Office outstations and observers at co-operating ancillary and climatological stations in the United Kingdom should be encouraged to submit notes or short accounts of interesting or remarkable weather phenomena without necessarily involving profound scientific analysis or explanation.

Our readers may expect therefore some gradual changes in the content and style of writing in future issues of the *Meteorological Magazine*, but not in the quality. The Editorial Board looks forward to receiving an increasing number of interesting contributions from meteorologists and climatologists wherever they may be working.

The Editorial Board at present consists of the following members:

R. P. W. Lewis	(Head of Library and Publications) (Editor and Chairman)
T. Davies	(Central Forecasting Office)
G. J. Jenkins	(c/o Central Directorate of Environmental Protection, Department of the Environment)
P. R. S. Salter	(Headquarters, RAF Strike Command)
P. G. Wickham	(Meteorological Office College).

551.507.352

The use of aircraft to study the atmosphere: the Hercules of the Meteorological Research Flight

By C. J. Readings

(Assistant Director (Professional Training))

Summary

The use of aircraft to study the structure of the atmosphere is illustrated by reference to the Hercules aircraft of the Meteorological Research Flight. In addition to describing the instrumental fittings in some detail the article outlines some of the uses of such a facility.

1. Introduction

It is now well over half a century since meteorologists first started using aircraft to study the structure of the atmosphere. In fact, before the network of balloon observations became established, aircraft were also used to take routine soundings of the atmosphere, recording temperature and humidity as a function of pressure (i.e. height) up to altitudes of around 8 km in unpressurized aircraft. This work is described by Sprigg (1939) and it is interesting to contrast the working conditions of pilots and observers in those early days, operating Bristol Bulldogs and Gloster Gladiators, with those experienced today when enclosed pressurized environments are the norm. In the interim, both aircraft and instruments have advanced considerably and the aim of this article is to give some indication of the facilities now available to atmospheric scientists.

Modern flying laboratories bear little resemblance to the early aircraft used for meteorological research, either in form or in content, being basically contemporary aircraft. Most have been modified so that some of their sensors (notably those used to measure wind and temperature) can be exposed remote from the influence of the airframe. 'Long noses' are common. They are also fitted with complex data recording and 'real time' display systems, enabling scientists not only to check that data are being recorded properly but also to monitor progress during flight, helping to ensure that opportunities are not missed and that the full potential of the facility is realized.

These aircraft are used to study a variety of atmospheric phenomena, ranging from 'classical' studies of phenomena such as fronts or wind structure to topics that have developed more recently (viz. the role of trace gases or the use of satellites). Areas of current interest to the Meteorological Office in which its research aircraft is involved, include:

the structure and dynamics of clouds,
the evolution of fronts and other synoptic and mesoscale phenomena,
the effect of topographic features on wind structure,
the transport of pollutants,
the amounts of trace gases present in the atmosphere,
radiative studies associated with the presence of aerosol,
the effect of clouds on radiative balance, and
the evaluation of proposed satellite remote atmospheric probing systems.

Of course this list only serves to give a general indication of current interests as the area of potential application is much wider.

In some instances a knowledge of basic meteorological variables such as wind, temperature and humidity suffices but in other areas information on cloud structure or chemical composition is required, so that these aircraft have to be equipped with a variety of instruments ranging from the basic (i.e. wind, temperature and humidity) to those designed to reveal details of cloud microstructure, aerosol content or chemical composition. The range has also been extended by current interest in remote sensing so that the generic term 'radiometer' could now be said to cover a wide variety of instruments.

Although on some occasions measurements gathered by flying at a single level along a single flight track are all that is required, in most instances information in three (or four) dimensions is needed. This inevitably leads to a conflict between the time available and the data requirements though normally one aircraft flying a series of different flight tracks does suffice. However, this basic capability occasionally has to be extended either by the use of dropsondes released by the aircraft or else by several aircraft collaborating in a single study. A recent example of the latter was KONTUR, an experimental study of convective activity in the German Bight, in which German and UK aircraft collaborated.

To illustrate the wide range of instruments that have to be carried for this work, one such facility will be described, namely the Hercules aircraft of the Meteorological Research Flight. In so doing, it is logical to group the instruments under general headings, namely basic meteorological variables, aerosol and cloud physics instruments, chemical sampling, radiometers and 'other'. A schematic diagram of the instrumental layout is given in Fig. 1 and Tables I–IV give details of the main experimental equipment carried by the aircraft.

2. The airframe

As can be seen from Fig. 2, the aircraft is a modified Lockheed C-130 'Hercules'. The radar antenna has been moved from its customary forward position just below the flight deck to a pod mounted above the cockpit, permitting a 7-metre 'nose' to be installed at the front of the aircraft. From this nose, meteorological variables such as temperature, pressure and undisturbed airflow, all of which could be adversely affected by the presence of the aircraft, are measured. Other instruments are mounted either on the fuselage or in special pods slung beneath the wings. Data are recorded on magnetic tape.

The aircraft has a ceiling of about 10 km and is capable of operating for some 14 hours, corresponding to a range of about 7500 km, though obviously these figures all depend on factors such as payload, operating altitude, etc. The aircraft is very well suited to studies covering the atmospheric boundary layer, the low stratosphere at high latitudes in winter and the troposphere in general, within clouds and in clear air.

3. Basic meteorological variables (Table I)

These comprise wind, temperature, humidity, position and altitude, and are measured by a combination of slow and fast response sensors. Wind is without doubt the most complex, depending as it does on the accurate determination of the difference between two relatively large vectors (i.e. air flow relative to the aircraft and the movement of the aircraft relative to the ground). The former is determined with the aid of two wind vanes which measure angles of attack and side-slip, coupled with air speed which is derived from a Pitot-static sensor linked to fast response capacitive-type pressure transducers. This probe is aerodynamically compensated to ensure that the static and dynamic pressure measurements are independent of the angle of incidence of the airflow. All these sensors are mounted on the end of the boom (see Fig. 1). Motion of the aircraft itself is measured by an inertial navigation system which gives the three velocity components together with pitch, roll and heading (see Broxmeyer 1964). Inertial

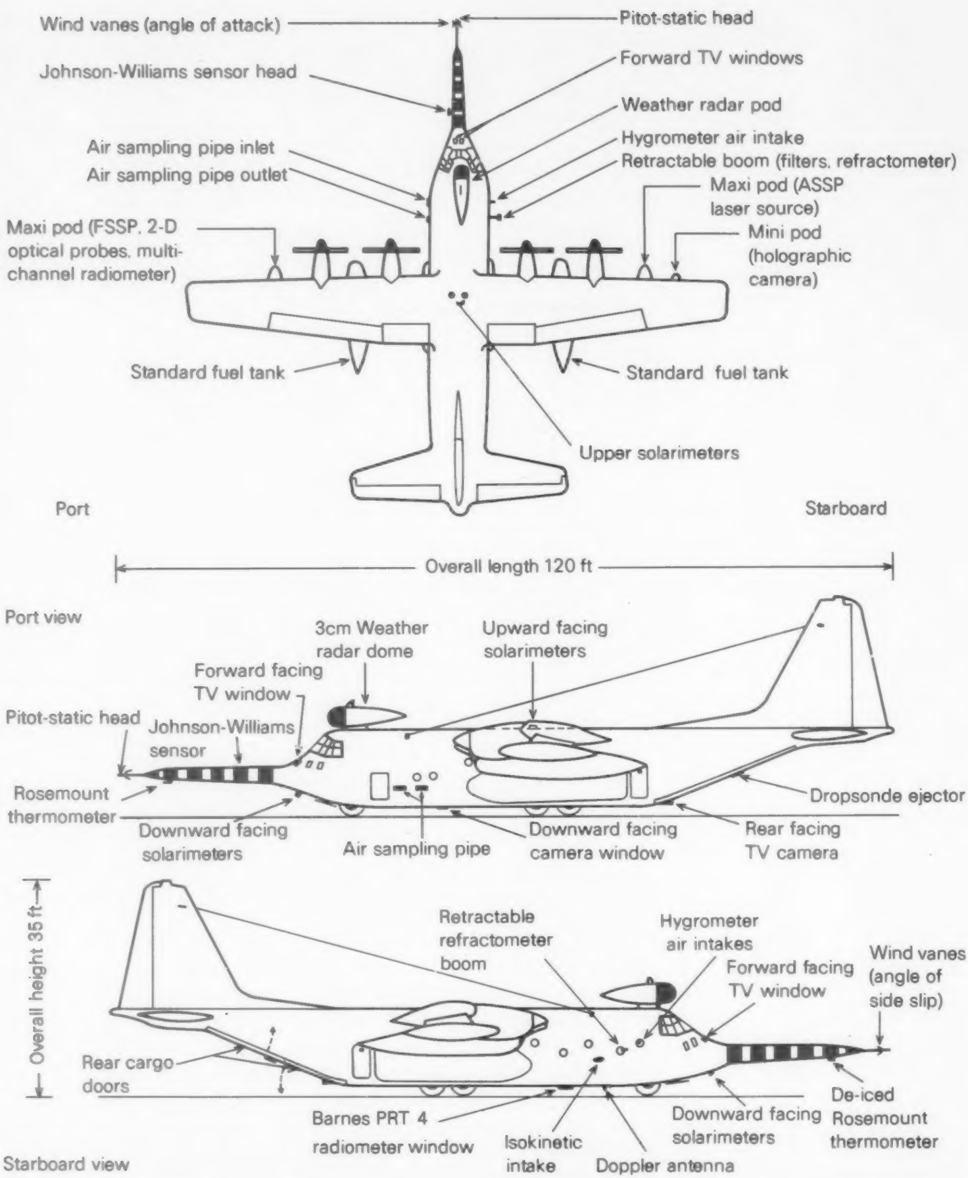

Figure 1. Schematic diagram showing the location of instruments on the Hercules aircraft as seen from above and from the sides.

Figure 2. General view of the Hercules aircraft of the Meteorological Research Flight.

Table I. *Basic meteorological variables*

Variable	Absolute accuracy	Resolution	Primary instrumental source	Remarks
Horizontal wind component	± 0.4 m s^{-1}	± 0.06 m s^{-1}	Pitot-static system, inertial platform, Doppler radar, Decca, Omega, Loran, angle of side-slip vane	Assumes full corrections applied including removal of INS drift
Vertical wind component	± 0.1 m s^{-1}	± 0.09 m s^{-1}	Pitot-static system, inertial platform, angle-of-attack vane	Assumes low-frequency errors removed by reference to changes in static pressure
Temperature	± 0.3°C	0.006°C	Platinum-resistance thermometer, Pitot-static system	Corrected for kinetic heating
Humidity mixing ratio	± 0.3 g kg^{-1}	± 0.02 g kg^{-1}	Refractometer, automatic hygrometer, manual hygrometer, platinum-resistance thermometer, Pitot-static system	Instruments cover different frequency ranges and different ambient conditions. Accuracy and resolution also vary with ambient conditions. Figures quoted refer to the lower levels of the atmosphere.
Geometric altitude	1%	0.8 m	Radar altimeter	
Pressure	± 1 mb	0.5 mb	Compensated static ports	

navigation systems (INS) are prone to slow drifts which must be removed if accurate winds are to be derived. For the horizontal components this is done by comparing INS positions with those derived from either a Decca Doppler radar or else a hyperbolic navigation system (i.e. Decca, Loran or Omega — see Meredith 1983). The latter are more accurate as they are not dependent on surface movement (viz. ocean currents). Drift errors in the vertical velocity are removed by reference to pressure changes. Fuller details of the various corrections may be found in Nicholls (1978) and Nicholls *et al.* (1983). Axford (1968) describes the way airflow and INS information are combined to produce wind data. Absolute accuracies of a few tenths of a metre per second are possible. Changes of a tenth of this can be detected up to frequencies of 10 Hz or more.

Temperature is measured by a platinum-resistance thermometer enclosed in a special housing. This is

also mounted on the boom as the aircraft can modify temperatures in its immediate vicinity. Corrections have to be made for both kinetic heating and the de-icing current which is applied to the housing (see Nicholls 1978). For high-frequency data (i.e. above 3 Hz) the variations of the response of the instrument (i.e. platinum element and housing) with frequency must be allowed for. This is done numerically using a technique developed by McCarthy (1973). Within clouds further problems arise as the thermometer becomes wet so that it tends to indicate 'wet-bulb' rather than 'dry-bulb' temperature (see Hess 1959).

Water vapour (i.e. specific humidity— see Hess 1959) is more difficult to measure than temperature as several different instruments are needed to meet all requirements. Two of these depend on the same physical process, namely the condensation of water vapour (as liquid or ice) on a cold surface. The temperature at which this starts to occur is the dew-point (or frost-point). With the manual hygrometer this is detected by an observer monitoring condensation on a metal surface cooled by liquid nitrogen (Cluley and Oliver 1978); with the other instrument it is done automatically using a photoelectric sensor to detect condensation on a mirror which is cooled by the Peltier effect (Nicholls 1978). Both instruments are required as the former can be used at lower temperatures and humidities. For high-frequency data (i.e. above 0.1 Hz) a microwave refractometer mounted on a retractable boom (see Fig. 1), is used. This measures the refractive index of air at centimetre wavelengths where it is dependent on the amount of water vapour present. Refractive index is also a function of temperature and pressure but as both of these parameters are measured it is a relatively simple matter to derive humidity (see McGavin and Vetter 1965). Calibration stability is achieved by matching these values (smoothed to remove high-frequency fluctuations) with those derived from the automatic hygrometer. The refractometer head has to be mounted on a retractable boom because the gold-plated microwave cavity should not be left exposed in all meteorological conditions (i.e. heavy rain, low temperature) though cloud droplets and ice crystals do not usually affect it.

Below 1500 m the height of the aircraft above the ground is measured directly with a radar altimeter; above this level the compensated pressure probe is used. Data from this instrument can be converted to height above the ground, with the aid of temperature and humidity profiles, by applying the hydrostatic equation (Hess 1959).

4. Aerosol and cloud physics instruments (Table II)

The aircraft is also equipped to study the structure of clouds and aerosols, using a variety of optical and other devices. Samples of solid matter present in the atmosphere can be collected on millipore filters (Johnson and Atkins 1975) mounted on the retractable boom (instead of the refractometer). These can subsequently be analysed in the laboratory to determine chemical and physical characteristics. An integrating nephelometer (Ruby and Waggoner 1981) mounted near the retractable boom provides information on the scattering properties of particles (principally in the range $0.1\mu m < r < 1\,\mu m$).

A Pollak counter (Nolan and Pollak 1946) monitors total particle concentrations (in the range $0.005\mu m < r < 0.1\mu m$). This is a derivative of the Wilson cloud chamber in which very high supersaturations ($\approx$300%) are applied by rapid decompression causing water to condense on any particles that are present. Reductions in transmission through the condensation chamber can be related to particle concentrations. The Cloud Condensation Nucleus counter (Lala and Jiusto 1977) is similar except that, instead of rapid expansion, a gradient of saturation is maintained. In this instrument, relatively low supersaturations, similar to those occurring in natural clouds, are applied. Thus only those nuclei which influence the microphysical properties of clouds are detected — i.e. generally large ($r > 0.2\mu m$) hygroscopic nuclei. For both of these instruments isokinetic (i.e. independent of particle size) sampling is required, so a specially shaped inlet port has been installed on the starboard side of the aircraft. Air

Table II. *Aerosol and cloud physics instrumentation*

Observable	Device	Size range *micrometres*	Remarks
Aerosol light scattering	Integrating nephelometer	$0.1<r<0.1$	Sampled via alleviator
Particle concentration	Pollak counter	$0.005<r<0.1$	Sampled via alleviator
Condensation nuclei	Cloud condensation nucleus counter	$r>0.2$	Sampled via alleviator
Number densities of cloud particles	ASSP and FSSP	$1<r\leq15$, $2<r<30$ or $3<r<45$	Choice of ranges. Size correct for water droplets only
	Cloud particle probe	$25<r<800$	
	Precipitation probe	$200<r<6400$	
	Holographic camera	$r>10$	Compact instantaneous 0.5 litre sample
Liquid water concentrations	Johnson–Williams meter	$r<50$	Largest drops shed by wire

flowing through this device is collected in an alleviator (basically a compression chamber) which brings samples up to cabin pressure prior to analysis.

A set of optical probes supply information on the distribution of cloud and precipitation particles (i.e. droplets, ice crystals etc. — see Mason 1962) within clouds. These instruments are mounted in the instrumented pods slung beneath the wings of the aircraft. The Knollenberg FSSP (Forward Scattering Spectrometer Probe) and ASSP (Axially Scattering Spectrometer Probe) measure the numbers of cloud particles lying in various size ranges by detecting the intensity of light scattered by individual particles as they traverse the sampling volume, assuming they are water droplets and that only one lies in the detector chamber at one time. A tape recorder logs the number of 'drops' detected in 15 size categories lying in one of 3 size ranges, namely $1<r<15\,\mu m$, $2<r<30\,\mu m$ or $3<r<45\,\mu m$ (Ryder 1976, Knollenberg 1976). Concentrations of liquid water within clouds may be obtained either by integrating these 'drop' size distributions or from a device called the Johnson–Williams meter. In this instrument the cooling of a hot wire exposed to the airstream caused by the evaporation of cloud drops colliding with and remaining attached to the wire is related to liquid water content (Strapp and Schemenauer 1982).

Information on the actual shapes of cloud and precipitation particles is provided by two-dimensional optical array probes (Knollenberg 1976) which are also fitted to an instrumented pod. One of these is capable of detecting larger cloud particles (i.e. $25\,\mu m<r<800\,\mu m$) while the other covers precipitation elements (i.e. $200\,\mu m<r<6.4$ mm). Images of the particles are projected on to 32-element photodiode detectors by laser beams. These arrays are scanned rapidly so that as the particle is advected through the system a two-dimensional image is built up. Further information is obtained with the aid of a holographic camera which records the interference patterns created by particles illuminated by a pulsed laser. The camera and the laser are installed in adjacent instrument pods (Fig. 1). Subsequently, particle images are reconstructed from the hologram in the laboratory using a CW laser which offers several advantages over the pulsed laser including better resolution. Particles larger than $10\,\mu m$ in radius can be studied (see Conway *et al.* 1982), the technique having much larger depths of field than is possible with conventional photography. Fig. 3 shows examples of the output from two of these optical devices.

5. Chemical sampling (Table III)

Several different gases may be detected by the equipment on the Hercules, including some of the oxides of nitrogen, sulphur dioxide and ozone. All enter the aircraft via the air-sampling pipe mounted on its port side (Fig. 1). Ozone detection is based on the ethylene–ozone chemiluminescence reaction

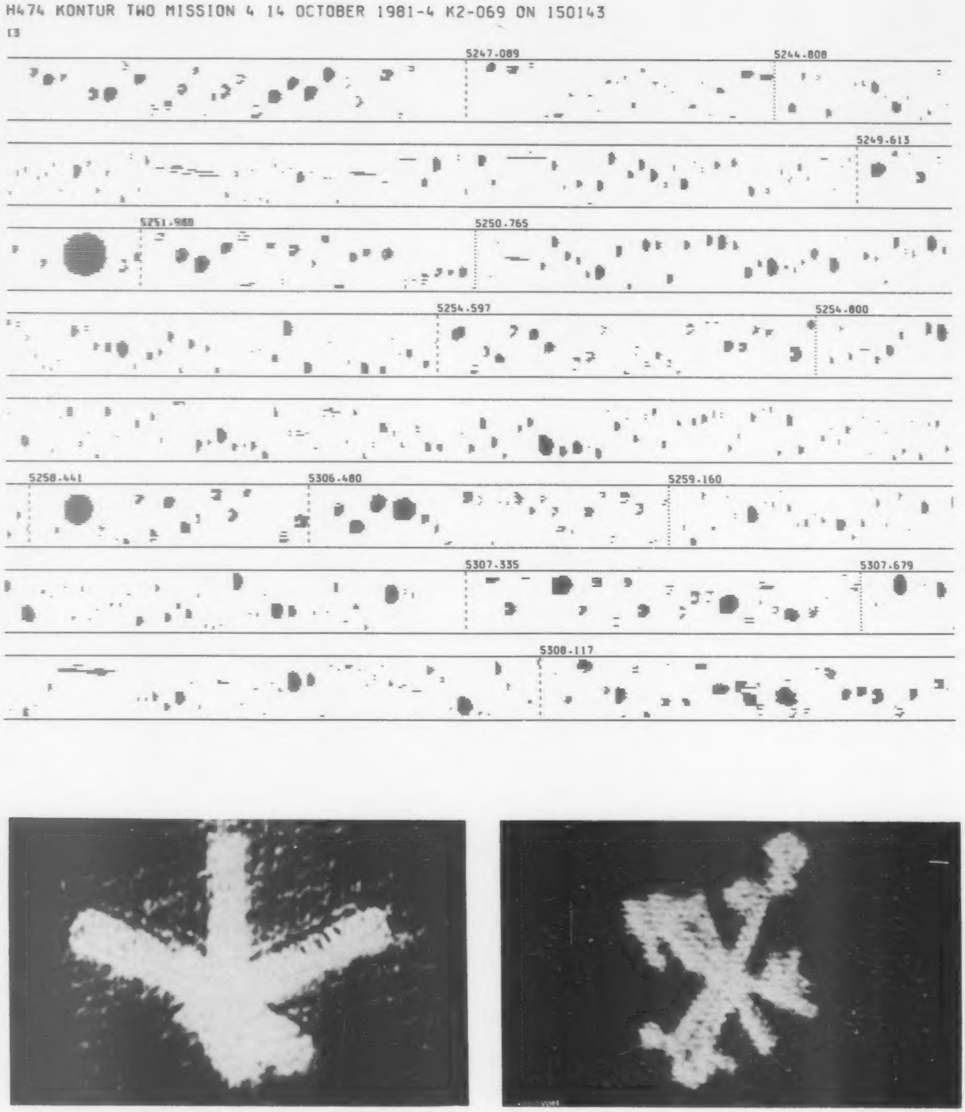

Figure 3. Examples of the output from two of the optical sensors. The top photograph shows reconstructed images of cloud droplets from one of the two-dimensional Knollenberg probes. The bottom two photographs show ice crystal images derived from the holographic equipment.

Table III. *Chemical sampling*

Observable	Device	Remarks
(a) Gases		
Sulphur compounds	Flame photometric analyses	Based on sulphur dimer emission in hydrogen flame
Nitrogen compounds	Chemiluminescent detector	Based on NO/O_3 chemiluminescent reaction: other nitrogen compounds converted to NO
Ozone	Chemiluminescent detector	Based on O_3/C_2H_4 chemiluminescent reaction
Tracers	Electron captive detector	Based on hydrogenations of tracer: two used are SF_6 and C_7F_{14}
General	(a) Gas chromatograph	Three-channel device capable of detecting freons (F-11, F-12), CCl_4, CH_3CCl_3, N_2O and CO_2
	(b) Bag samples	Laboratory analysis
(b) Particulate matter	Millipore filters, laboratory analysis	Possible to detect Ca^{++}, Mg^{++}, Na^+, NH_4^+, K^+, Cl^-, NO_3^-, SO_4^{--}
(c) Cloud liquid water	Samples collected in flight, laboratory analysis	pH can be measured in real time

(McKee 1976), while the detection of nitrogen relies on the nitric oxide-ozone chemiluminescence reaction (Stedman *et al.* 1972). The latter is specific to nitric oxide but the other compounds of nitrogen (i.e. nitrogen dioxide, nitric acid and ammonia) can also be detected by converting them to nitric oxide before mixing the sample with ozone. For all but nitrogen dioxide this is achieved by passing the sample through a steel tube at a temperature lying between 600°C and 800°C. Nitrogen dioxide is reduced to nitric oxide with the aid of a molybdenum catalyst (Winer *et al.* 1974). The detection of sulphur depends on the emission from sulphur dimers when the sample is burnt in a hydrogen flame (Tanner *et al.* 1980). Any sulphur compound (including aerosol sulphuric acid and ammonium sulphate) which is converted to the dimer in the flame is detected — solid matter being removed by filtering (optional) prior to analysis. In all cases (see Table III) commercial instruments are used, modified so that the pressure and temperature of the intake gas can be monitored.

There are in addition to the chemical detectors described above a three-channel gas chromatograph and a tracer detector on board the aircraft. The former can measure a selection of (or all) the following atmospheric trace gases — fluorotrichloromethane (F-11), difluorodichloromethane (F-12), carbon tetrachloride (CCl_4), methyl chloroform (CH_3CCl_3), nitrous oxide (N_2O) and carbon dioxide (CO_2), depending on the choice of column materials and operating conditions (Bamber *et al.* 1984). The tracer detector is a two-channel electron capture device developed specifically to measure concentrations of sulphur hexafluoride and perfluoromethyl-cyclohexane (Blackburn and Dear 1984) which are used to 'label' parcels of air for long-range (i.e. hundreds of kilometres) tracking.

These facilities are backed by a bag sampling facility which enables 'Sarron' bags to be filled with air samples for subsequent analysis in the laboratory. Somewhat more sophisticated are the stainless steel bottles which are also available to take air samples. These have been used to validate the real-time gas chromatograph data and to measure hydrocarbons (Bamber *et al.* 1984). The millipore filters (see above) can be used to collect samples of solid particulate matter. Among the ions that can be measured are:

$$Ca^{++}, Mg^{++}, Na^{+}, NH_4^{+}, K^{+}, Cl^{-}, NO_3^{-} \text{ and } SO_4^{--}.$$

Cloud-water samples may also be taken either in sample bottles for subsequent analysis or else through pipes installed in the aircraft to a pH meter which indicates the sample's acidity in real time. Larger droplets (including actual precipitation) are collected at a bend in the air sampling tube; smaller droplets (i.e. $r<10\mu m$) remaining in the airstream are swirled to the edges of the tube by a fan where they collect in small channels (Walters *et al.* 1983).

6. Dropsonde facility

The Hercules is equipped to release and record data from dropsondes which measure temperature (thermistor), humidity (carbon hygristor) and pressure (solid-state capacitor) during their descent. The dropsondes are ejected from the rear of the aircraft and fall at about 12 m s^{-1} on a parachute designed to follow horizontal airflow. A typical descent takes about 15 minutes. Information from the sonde is relayed back to the aircraft via a UHF radio link. Included in this data stream are Loran C signals (Meredith 1983) detected by the sonde. These give the sonde's position as a function of time, enabling wind profiles to be derived which, averaged vertically over depths of 600 m or so, are accurate to better than 0.4 m s^{-1}. Temperature is measured to within ±0.5 °C, relative humidity to ±5% (over the range 30% to 95%) and pressure to ±0.2 mb. Further details may be found in Ryder *et al.* (1983).

7. Radiometers (Table IV)

Upward and downward facing broad-band radiometers enable fluxes of short-wave (i.e. solar) and long-wave (i.e. terrestrial) radiation to be measured (see Fig. 1). The pyranometers cover the spectral range 0.3 μm to 3 μm while the pyrgeometers cover the range 4 μm to 50 μm. Both types use blackened junctions of thermopiles to detect the radiation. However, in the pyranometer these are covered by two concentric glass domes, while for the pyrgeometer a single-coated silicon dome suffices. Various corrections have to be applied to the instruments to allow for aircraft attitude and ambient conditions. The pyrgeometer in particular is very difficult to operate successfully, the corrections proving quite complex (Albrecht and Cox 1977).

In addition to these broad-band, wide-angle (viz. ±90° subject to cosine response) radiometers, there is also a narrow angle (≈2°) downward-facing long-wave radiometer covering the range from 8 μm to 14 μm. This is intended to measure sea surface temperature. It is calibrated in flight by placing a black body of known temperature in its field of view — this is not practicable with the broad-band, wide-angle radiometers as they are mounted on the outside of the aircraft. To derive sea surface temperature further corrections are required to account for absorption and emission between the aircraft and the surface and the emissivity of the surface (see Nicholls 1978).

Apart from these radiometers there is a multi-channel radiometer mounted in one of the instrumented pods. This is a 16-channel device (i.e. 4 detectors each monitoring 4 separate channels) capable of recording 4 channels simultaneously with a field of view of only 1½°. A mirror provides a scanning capability so that the radiometers can view vertically upwards (i.e. zenith) or between nadir and nadir minus 60°. Triglycine sulphate (TGS) and lead sulphide detectors are used to detect the radiation so

Table IV. *Radiometers*

Device	Nature	Spectral coverage *micrometres*	Remarks
Pyranometer	Broad-band, wide angle, short-wave radiation	0.3–3	Spectral range dependent on choice of domes. Upward and downward facing
Pyrgeometer	Broad-band, wide angle, long-wave radiation	4.0–50	Upward and downward facing
Radiation thermometer	Long-wave, narrow angle (≈2°)	8–14	Downward facing, intended to measure sea surface temperature
Multi-channel	Narrow angle (≈1½°), narrow band, 16 channels (4 × 4)	Narrow band 1–50	Spectral range depends on choice of detectors. Covers zenith and nadir to nadir — 60°

channels can be established in both the infra-red (i.e. 8 μm to 50 μm) and the near infra-red (i.e. 1 μm to 3 μm) regions of the electromagnetic spectrum respectively. The radiometer can be used with very narrow-band filters (viz. $\approx$0.02 μm in the near infra-red). It started life as the prototype of an instrument flown on a Nimbus satellite and has recently been extensively modified after earlier use on the Canberra aircraft of the Meteorological Research Flight (Coffey 1977). In-flight calibration is provided by two black bodies and a solar diffuser.

8. Other facilities including data recording

As well as the instruments described above, the aircraft carries both forward and downward facing cameras. These can take pictures automatically at regular intervals; in fact the forward camera has a cine capability. Information provided by these two devices is supplemented by the use of hand-held cameras and three video cameras, two of which face forwards and one backwards.

A 3 cm weather radar is housed in the pod situated above the flight deck (Fig. 1). This has a forward field of view (i.e. $\pm 90°$) and can scan at elevations within $\pm 15°$. It has three display ranges (viz. 0–45 km, 0–90 km and 0–280 km) and a rainfall detection threshold of 1 mm h^{-1}. The radar can be programmed to execute a sequence of measurements at different ranges and elevations for later analysis of photographs of the display.

Information from the various instruments is normally recorded in flight on magnetic tape which is later transcribed to a computer-compatible format. Data acquisition is controlled by a Motorola 6809 microprocessor and is capable of handling 33 000 bits of information per second (up to 128 channels, both analogue and digital data). Operators monitor progress via a keyboard and a visual display unit. There is an 'event mark' facility with input buttons sited at locations distributed all over the aircraft. The system is linked to a real-time display unit which enables scientists to carry out preliminary analyses as well as monitoring progress during the flight.

9. Concluding remarks

On an experimental aircraft such as the Hercules, the instrumental fittings are continually evolving. This is, of course, to be expected as new techniques are continually being developed and existing ones improved, making it possible to extend the aircraft's basic capability and to maintain it by replacing items that are worn out or difficult to maintain. Ideally these should all be standard items as these are generally easier to acquire and maintain, but this is not always possible. Other possibilities are: building instruments to designs obtained from other scientists; using equipment supplied by collaborators; or designing, developing and manufacturing in-house. The last is the least attractive as it carries a high element of risk and makes extensive use of scarce resources. Examples of all three types of installation can be found on the Hercules. Of course, what has been presented here represents the current situation. New installations are always in the pipeline and amongst those already well advanced are a new inertial navigation system, a radiometer for measuring temperatures within clouds and a new device for measuring total water content based on the Lyman-alpha hygrometer (Buck 1976).

The particular aircraft considered here, although probably the most extensively equipped for atmospheric research, is not unique and there are similar facilities elsewhere though not many approach the scale of the Hercules. Thus the Natural Environment Research Council has recently acquired a small Cessna aircraft primarily for remote sensing of the surface. However, there are extensive facilities for atmospheric research based on aircraft in several countries including West Germany (e.g. DFVLR, Institut für Physik der Atmosphäre, Oberpfaffenhofen) and the USA (e.g. the National Center for

Atmospheric Research, Boulder, Colorado and the National Oceanic and Atmospheric Administration, Washington D.C.). Some facilities have more than one aircraft available so, although each individually may have a more limited capability than the Hercules, the total capability will be the same or greater. Aircraft are very adaptable, being quite capable of carrying a whole series of different instruments, only a sample of which have been referred to here (the descriptions have, of necessity, had to be brief and are intended to be supplemented by the references). The areas of possible interest are also vast so it is only possible in an article of this nature to give a general indication of the potential of such a facility.

The reader should also bear in mind the man–machine mix. Aircraft are useless unless they are in the right place at the right time. This is very dependent on the skills of the aircrew who operate the aircraft and the scientists who direct its use, often with inadequate information. It takes years of experience to develop the skills necessary to make optimum use of an aircraft by learning, for example, how to interpret instruments such as radars or to recognize what is worth studying and what is not — the eyes of the scientist coupled with his ability to communicate are of crucial importance yet it is all too easy to gloss over this aspect. The photograph of the aviator in Sprigg's (1939) article makes the point better than any text.

Acknowledgements

I wish to express my gratitude to colleagues, both scientists and aircrew, who have provided information and advice during the preparation of this paper.

References

Albrecht, B. and Cox, S. K.	1977	Procedures for improving pyrgeometer performance. *J Appl Meteorol*, **16**, 188–197.
Axford, D. N.	1968	On the accuracy of wind measurements using an inertial platform in an aircraft, and an example of the measurement of the vertical mesostructure of the atmosphere. *J Appl Meteorol*, **7**, 645–666.
Bamber, D. J., Healey, P. G. W., Jones, B. M. R., Penkett, S. A., Tuck, A. F. and Vaughan, G.	1984	Vertical profiles of tropospheric gases: Chemical consequences of stratospheric intrusions. *Atmos Environ*, **18**, 1759–1766.
Blackburn, A. J. and Dear, D. J. A.	(1984)	A design for an airborne sulphur hexafluoride tracer detector. (Submitted to *Atmos Environ*.)
Broxmeyer, C.	1964	Inertial navigation systems. New York, McGraw-Hill Book Co.
Buck, A. L.	1976	The variable-path Lyman-alpha hygrometer and its operating characteristics. *Bull Am Meteorol Soc*, **57**, 1113–1118.
Cluley, A. P. and Oliver, M. J.	1978	Aircraft measurements of humidity in the low stratosphere over southern England. *Q J R Meteorol Soc*, **104**, 511–526.
Coffey, M. T.	1977	Water vapour absorption in the 10–12 μm atmospheric window. *Q J R Meteorol Soc*, **103**, 685–692.
Conway, B. J., Caughey, S. J., Bentley, A. N. and Turton, J. D.	1982	Ground-based and airborne holography of ice and water clouds. *Atmos Environ*, **16**, 1193–1207.
Hess, S. L.	1959	Introduction to theoretical meteorology. New York, Henry Holt and Company.
Johnson, D. A. and Atkins, D. H. F.	1975	An airborne system for the sampling and analysis of sulfur dioxide and atmospheric aerosols. *Atmos Environ*, **9**, 825–829.
Knollenberg, R. G.	1976	Three new instruments for cloud physics measurements: the 2-D spectrometer, the forward scattering spectrometer probe and the active scattering aerosol spectrometer. Boston, Massachusetts, American Meteorological Society. International Cloud Physics Conference, July 26–30, 1976, Boulder, Colorado, USA, 554–561.

Lala, G. G. and Jiusto, J. E. 1977 An automatic light scattering CCN counter. *J Appl Meteorol*, **16**, 413–418.

McCarthy, J. 1973 A method for correcting airborne temperature data for sensor response time. *J Appl Meteorol*, **12**, 211–214.

McGavin, R. E. and Vetter, M. J. 1965 Radio refractometry and its potential for humidity studies. *In* Wexler, A. (ed.). Humidity and moisture. Measurement and control in science and industry. Based on papers presented at the 1963 International Symposium on Humidity and Moisture, Washington, D.C. Vol. 2, Applications (ed. Amdur, E. J.). New York, Reinhold Publishing Corporation, 553–560.

McKee, H. C. 1976 Collaborative testing of methods to measure air pollutants. III, Chemiluminescent method for ozone: determination of precision. *J Air Pollut Control Assoc*, **26**, 124–135.

Mason, B. J. 1962 Clouds, rain and rainmaking. Cambridge, Cambridge University Press.

Meredith, J. S. 1983 Global navigation systems (special issue). *Proc Inst Electr Electron Eng*, **71**, 1123–1227.

Nicholls, S. 1978 Measurements of turbulence by an instrumented aircraft in a convective atmospheric boundary layer over the sea. *Q J R Meteorol Soc*, **104**, 653–676.

Nicholls, S., Brummer, B., Fielder, F., Grant, A., Hauf, T., Jenkins, G., Readings, C. and Shaw, W. 1983 The structure of the turbulent atmospheric boundary layer. *Philos Trans R Soc*, A, **308**, 291–309.

Nolan, P. J. and Pollak, L. W. 1946 The calibration of a photo-electric nucleus counter. *Proc R Ir Acad*, **51A**, 9–31.

Ruby, M. G. and Waggoner, A. P. 1981 Intercomparison of integrating nephelometer measurements. Washington, American Chemical Society, *Environ Sci Technol*, **15**, 109–113.

Ryder, P. 1976 The measurement of cloud droplet spectra. Boston, Massachusetts, American Meteorological Society. International Cloud Physics Conference, July 26–30, 1976, Boulder, Colorado, USA, 576–580.

Ryder, P., Lewis, A. F. and Bennetts, D. A. 1983 The NAVAID dropsonde. *Meteorol Mag*, **112**, 367–380.

Sprigg, T. S. 1939 The flying weather-man, *Flying*, **3**, 7–8, 16–17.

Stedman, D. H., Daby, E. E., Stuhl, F. and Niki, H. 1972 Analysis of ozone and nitric oxide by a chemiluminescent method in laboratory and atmospheric studies of photochemical smog. *J Air Pollut Control Assoc*, **22**, 260–263.

Strapp, J. W. and Schemenauer, R. S. 1982 Calibrations of Johnson–Williams liquid water content meters in a high-speed icing tunnel. *J Appl Meteorol*, **21**, 98–108.

Tanner, R. L., D'Ottavio, T., Garber, R. and Newman, L. 1980 Determination of ambient aerosol sulfur using a continuous flame photometric detection system. I. Sampling system for aerosol sulfate and sulfuric acid. *Atmos Environ*, **14**, 121–127.

Walters, P. T., Moore, M. J. and Webb, A. H. 1983 A separator for obtaining samples of cloud water in aircraft. *Atmos Environ*, **17**, 1083–1091.

Winer, A. M., Peters, J. W., Smith, J. P. and Pitts, J. N. 1974 Response of commercial chemiluminescent NO_x analysers to other nitrogen compounds. *Environ Sci Tech*, **8**, 1118.

551.509.314:551.509.322:624.21/.8

Techniques for forecasting the occurrence of strong winds over the Severn Bridge

By K. C. Wright

(Meteorological Office, Bracknell)

Summary

In an attempt to find useful predictors of the occurrence of strong winds over the Severn Bridge, 503 gusts of 30 kn or more over a 10-year period were analysed. As a result it is suggested that, during periods of cyclonicity, the mean of estimates of the gradient wind and the 900 mb wind provides a better approximation to the actual wind than the gradient wind alone. Furthermore, where adjacent high ground causes severe distortion to the air flow, the lee-wave parameters may be combined to provide an additional predictor.

1. Introduction

The project was started as a result of the introduction (at the meteorological office at Upavon in Wiltshire) of a requirement to issue warnings to the motorway police at Almondsbury whenever frequent gusts of 30 kn or more were expected over the Severn Bridge.

The bridge is situated about 17 km north-north-west of Bristol and is a little over 60 m above the River Severn. The south-west to north-east alignment of the estuary and the distribution of the high ground within 70 km of the bridge leads to four sectors with different topographical features predominating (see Fig. 1). These are:

(1) *North-east.* This contains, on either side of the river, the Cotswold Hills and the Malvern Hills, much of which are above 200 m.

(2) *South-east.* Nearly all this sector is between 100 and 200 m above mean sea level and consists of the south Cotswold Hills, the north-west edge of Salisbury Plain and most of the Mendip Hills.

(3) *South-west.* This is mostly either the river estuary or the adjacent low-lying land.

(4) *North-west.* Much of this sector, which includes the Black Mountains and the Brecon Beacons, is above 400 m.

2. Methodology

2.1 *The data*

The wind speed over the bridge was recorded on a Meteorological Office Mark IV electrical anemograph. The cup sensors are situated on the bridge between the toll booths and the first main tower and are fixed to a post some 4 m above the roadway — a far from ideal exposure! Furthermore, the recording system is sited some 7 km to the south-east at Almondsbury police station. These units are connected by telephone cables whose resistive and capacitive properties are unknown. It is estimated by the Meteorological Office Maintenance Organization that the system may have produced anomalous results, perhaps leading to a reduction of up to 10% in the recorded speed.

Gust data were obtained from anemographs from the period 1973–82 inclusive, but excluding 1980, for which data were not available.

2.2 *The analysis*

The effective predictors of measured gusts from a site near the surface are expected to be those which reflect the large-scale dynamical and thermal structures. Approximations are therefore required to the

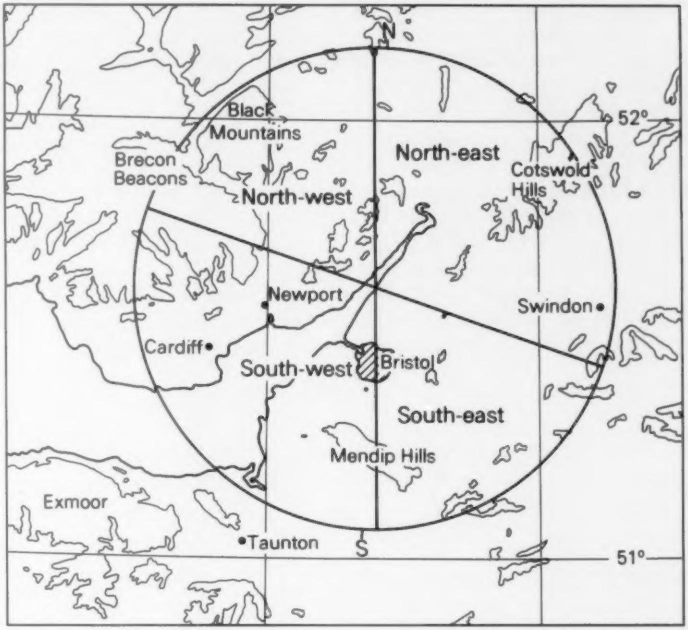

Figure 1. Map of high ground (over 200 m) within 70 km of the Severn Bridge showing sectors used in meteorological analysis.

actual winds and to the low-level temperature lapse rate. In addition, account must be taken of the effects of local topography. The basic method is to stratify the gust data with respect to these variables.

The usual approximation to the actual wind, the gradient wind, was estimated from UK synoptic charts (scale 1:10^6) to the nearest 5 kn, by applying corrections to the isobaric gradient for curvature of the isobars and any isallobaric effect. In view of the requirement for forecasting frequent gusts of over 30 kn, only those occasions when the gradient wind was 35 kn or more were noted so that gusts caused primarily by shower activity were ignored.

The effects of topography were isolated by classifying the gusts into 5° subsets according to the direction of the 900 mb ($\approx$900 m) flow, D_{900}. To this end, interpolations were made for space and time from the six-hourly upper-wind reports (usually Camborne, Crawley and Aughton as, fortuitously, the Severn Bridge lies close to the centroid of the triangle with its vertices at these locations).

Similarly, a representative radiosonde ascent (or the median of several ascents) was used to provide a measure of the low-level instability.

The data were analysed using the forward step-wise linear regression computer program of the biomedical statistical package (University of California 1984) with the objective of reducing the standard error of the residuals, SER, (i.e. actual gust minus expected gust) from the predicting equations to less than 5 kn.

The initial choice of predictors was:

(a) *The low-level temperature lapse over 50 mb (ΔT).* The temperature lapse was calculated by using the difference between the temperature at 50 mb ($\approx$450 m) above the surface from the representative

ascent(s) and the surface temperature recorded at Bristol (i.e. Filton until 1978, then the Weather Centre). This parameter proved more effective, however, if the range was truncated to 1.5–4.5°C inclusive, as neither superadiabatic nor very stable conditions were expected to prevail during strong winds, especially high above a river estuary.

(b) *The gradient wind* (G_r). Analysis of the south-westerly data highlighted the inadequacy of a simple gradient wind approximation as a predictor, particularly in cases of strong cyclonic flow. A comparison of these events with respect to the estimated 900 m wind (U_{900}) showed that, if the gradient wind was greater than U_{900} by 10 kn or more and there was no anticyclonic curvature, then the standard error of the residuals (SER) was much greater at 4.9 kn than at the 3.1 kn for the other occasions.

In order to reduce the SER for the former cases, the curvature rule shown in Table I was adopted to provide a more effective estimate of the actual wind, G_a.

This refinement reduced the SER for cyclonic or straight isobars to 3.7 kn. A plot of all the gust data with respect to G_a and ΔT showed that there was some divergence as G_a increased in value. This effect was negated for the linear regression program by adopting the transform:

$$\Delta T_t = \Delta T \{0.5 + (G_a - 15)/40\}.$$

There also appeared to be some slight curvilinearity as G_a increased, causing the expected gust (E) to be greater than G_a when G_a is less than 40 kn. This effect was corrected by the adoption of:

$$G_t = nG_a + (1 - n)U_{900},$$

where $n = 0.56 - 0.0025\,G_a$. For practical purposes, however, the latter transform may be ignored with no significant loss of accuracy below about 100 kn.

3. Results

As the gusts were grouped into 5° subsets according to D_{900} it was possible to optimize the limits of each of the different geographical sectors. These are shown in Table II.

3.1 *Region 1: south-west and north-east sectors (293 gusts)*

The linear regression program produced the following equation for expected gusts (E):

$$E = 0.63G_a + 2.6\,\Delta T_t \{0.5 + (G_a - 15)/40\} + 1.2,$$

generating the nomogram shown in Fig. 2. This has validity only for values of G_a of 35 kn or more.

The gusts for this sector were regrouped according to the type of terrain within 70 km of the bridge, but the only significant differences occur at high values of G_a; see Table III.

Hence for practical purposes it is sufficient, when $G_a > 70$ kn, to add 4 kn if D_{900} is 210–260° and subtract 4 kn if D_{900} is 180–200° or 270–280°.

3.2 *Region 2: north-west sector (126 gusts)*

The previous methodology used to provide an estimate of the actual wind (i.e. G_a) proved inadequate for this sector owing to the severe distortion to the flow caused by the Welsh mountains. A more

Table I. *Adjustment to the gradient wind, G_r (if $G_r - U_{900} \geq 10$ kn) to provide a closer approximation to the actual wind, G_a*

Curvature	Gradient wind, G_r *knots*	Adjustment
Anticyclonic	All	$G_a = G_r$
Cyclonic	>40	$G_a = (G_r + U_{900})/2$
'Straight'	<65	$G_a = G_r - 5$
'Straight'	≥65	$G_a = G_r - 10$

'Straight' isobars have a radius of curvature of more than 1200 nautical miles.

Table II. *Specification of geographical sectors*

Region	Sector	900 mb wind direction, D_{900} *degrees*
1	South-west	180–285
	North-east	360–105
2	North-west	290–355
3	South-east	110–175

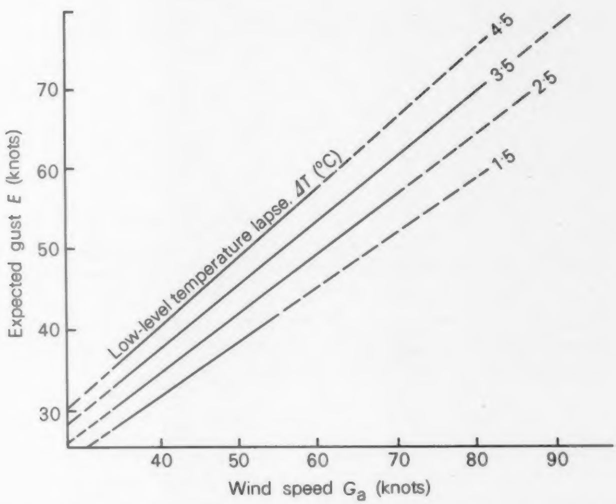

Figure 2. Nomograms for obtaining the maximum gust over the Severn Bridge if the 900 mb wind direction is south-west (180–285°) or north-east (360–105°), where ΔT_l (°C) is the temperature lapse through the lowest 50 mb. The lines are drawn from the equation:

$$E = 0.63G_a + 2.6 \times \Delta T_l \{0.5 + (G_a - 15)/40\} + 1.2.$$

Pecked lines indicate extrapolated data.

Table III. *Variation in expected gust, E (knots) with respect to terrain traversed*

900 mb wind direction, D_{900} *degrees*	Type of terrain	Number of gusts	Standard error of residuals	Expected gust if $-\Delta T = 4\frac{1}{2}$ °C $G_a = 40$	$G_a = 80$
210–260	Sea track or little high ground	165	3.4	40	79
360–095	Land track, but little high ground perpendicular to wind flow	48	3.4	39	75
180–200 and 270–285	Land track with significant high ground	80	3.0	39	71
All	—	293	3.3	39	75

objective methodology was adopted in order to minimize the standard error of the residuals. After some experimentation the following algorithm was adopted:

Step 1. Estimate G_1 from the surface pressure difference between Plymouth (Mount Batten) and Birmingham (Elmdon) with corrections for curvature and variation in D_{900}.

Step 2. Estimate G_2 by correcting G_1 for the isallobaric gradient (using the pressure tendencies at Aberporth and Boscombe Down), but only if the isobaric curvature is cyclonic.

Step 3. Let north-west wind be $G_{nw} = (G_2 + U_{900})/2$.

These changes reduced the standard error of the residuals to the values shown in Table IV.

Table IV. *Reduction of the standard error of the residuals (SER) in the calculation of the actual wind for the north-west sector, G_{nw}*

Approximation to actual wind	G_a	G_1	G_2	G_{nw}
SER	7.9	6.7	6.6	5.7

In an attempt to understand the role of atmospheric stability, the residuals (from the results of the linear regression analysis), actual gust minus expected gust, were plotted against the lee-wave parameters of wavelength (λ) and vertical velocity (C_1). These were calculated using Casswell's technique (Casswell 1966). Isotachs were drawn at 5 kn intervals and optimized so that the mean of each group of residuals was as close as possible to its coefficient (see Fig. 3). The introduction of this coefficient, a linear lee-wave index (L), further reduced the SER from 5.7 to 4.0 kn and resulted in the following equation for predicting gusts in north-westerly flow:

$$E = 0.77\,G_{nw} + 2.4\,\Delta T + 1.0L - 7.2$$

and the nomograms shown in Fig. 3 were constructed. The technique, therefore, for winds in this sector is to obtain a first estimate of the expected gust using Fig. 3(a) and then apply the lee-wave correction, if any, obtained from Fig. 3(b). It should be noted, however, that the value of L will change along with changes in stability in the lower troposphere, typically by 5 kn every 6 hours. Minimum values (i.e. $\leqslant -10$ kn) occur at about 100 nautical miles behind a cold front as opposed to about 280 nautical miles for maximum values (i.e. $\geqslant 5$ kn). Although this procedure reduced the SER, the variation within each subset of L could still be large.

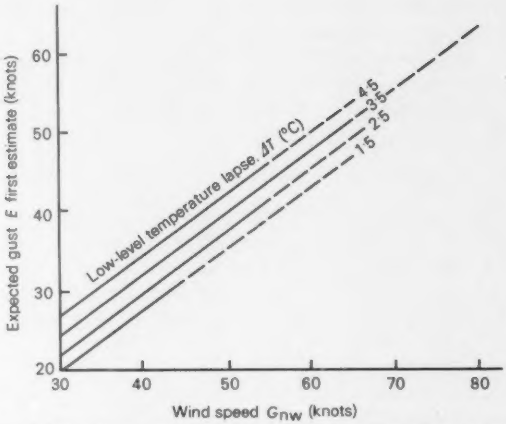

Figure 3(a). Nomograms for obtaining the maximum gust over the Severn Bridge if the 900 mb wind direction is north-west (290–355°), before adding the lee-wave correction, L (see Fig. 3(b)). ΔT(°C) is the temperature lapse through the lowest 50 mb. The lines are drawn from the equation: $E = 0.77G_{nw} + 2.4 \times \Delta T - 7.2$. **Pecked lines indicate extrapolated data.**

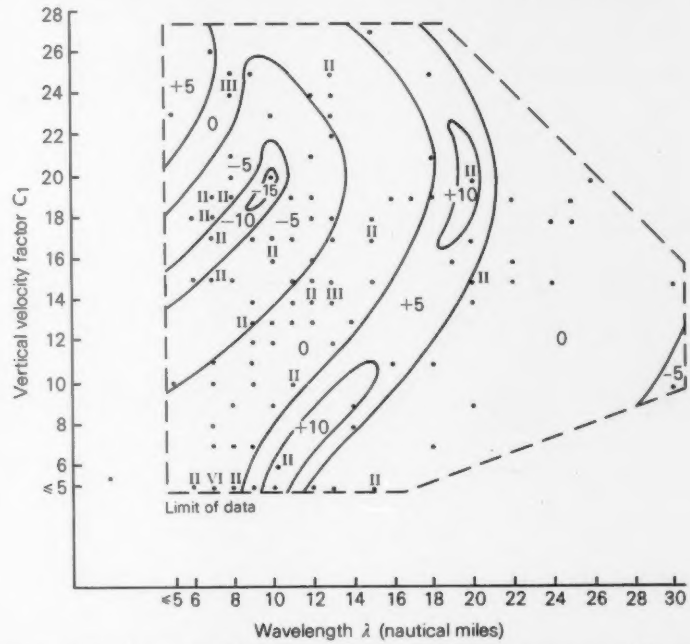

Figure 3(b). Nomogram for obtaining values of the lee-wave correction, L. Each point represents a gust. Roman numerals indicate the number of gusts with the same values of λ and C_1. Values of λ and C_1 are obtained from a representative ascent using the technique devised by Casswell (1966).

The synoptic situations were also checked when the gradient wind was below 30 kn, but the lee-wave effect disappeared completely when G_{nw} was less than 29 kn.

In view of the effectiveness of the above index, the lee-wave parameters were calculated for the other sectors. There was, however, no discernible pattern when they were similarly plotted against the residuals, nor any significant correlation in the linear regression.

3.3 *Region 3: south-east sector (84 gusts)*

Although there is very little ground above 200 m to the south-east, it apparently has the effect of reducing the gusts by at least 15–25 kn compared with similar conditions and terrain in the south-west sector. Furthermore, no dependence on any low-level temperature lapse was detected. Although the quantity of gust data is relatively small, there is some justification for subdividing the sector, for, as is shown in Table V (and the nomogram in Fig. 4), there is a significant variation within the sector.

Table V. *Subdivision of south-east sector*

D_{900}	Number of gusts	SER	Formula for the expected gust, E, if $G_r = 50$	
degrees				
110–115	21	2.9	$E = 0.76G_r - 5.3$	33
120–175	63	3.2	$E = 0.57G_r - 3.5$	25
All	84	4.1	$E = 0.77G_r - 10.4$	28

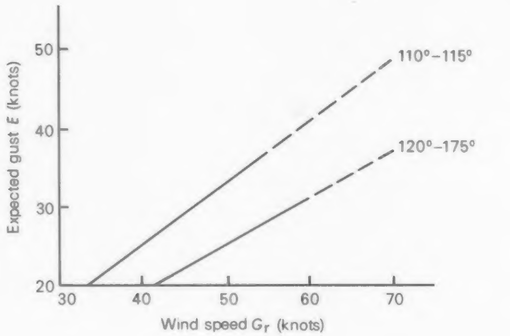

Figure 4. Nomogram for obtaining the maximum gust over the Severn Bridge if the 900 mb wind direction is south-east (110–175°). Lines are drawn from the equations:

$$E = 0.76G_r - 5.3 \text{ for } 110\text{–}115^\circ$$
$$\text{and } E = 0.57G_r - 3.5 \text{ for } 120\text{–}175^\circ.$$

Pecked lines indicate extrapolated data.

Table VI. *Wind gradient required for an expected gust of 43 kn and ΔT or $\Delta T_t = 3.0°C$*

Direction	Lee-wave index, L	Wind *knots*
North-west	10	$G_{nw} = 33$
South-west and north-east	—	$G_a = 50$
North-west	−15	$G_{nw} = 58$
South-east (120–175°)	—	$G_r = 82$

4. Conclusions

To illustrate the wide differences between the sectors Table VI shows the actual wind speed required for an expected gust of 43 kn (i.e. gale force), if the low-level temperature lapse is 3.0°C.

Of the current techniques recommended for the forecasting of maximum gusts, it is believed that none use any parameters other than an approximation (usually an estimate of the geostrophic wind or the gradient wind) and a low-level temperature lapse rate. As has been shown by the analysis of the data, the gradient and geostrophic wind approximations are inadequate during cyclonic synoptic situations (at least in locations such as the Severn Bridge, where there is significant high ground within about 50 km). In such situations a mean of estimates of the gradient wind and the 900 mb wind provides a better approximation to the actual wind. Secondly, where the adjacent high ground causes severe distortion to the air flow (as with the north-west sector for the Severn Bridge) a lee-wave index may provide an additional predictor.

Although the preceding analysis is based on data for 503 gusts, the predicting equations should be verified by a set of independent data. It is hoped that gust data currently being gleaned from the anemograph charts for 1982–83 will be used for this purpose.

5. Acknowledgements

The author would like to thank his many colleagues for their help and advice during the period of this project.

References

Casswell, S. A. 1966 A simplified calculation of maximum vertical velocities in mountain lee waves. *Meteorol Mag,* **95,** 68–80.

University of California 1984 Biomedical computer programs, P-series. Los Angeles, University of California, Health Sciences Computing Facility.

Reviews

Remote sounding of atmospheres, by J. T. Houghton, F. W. Taylor and C. D. Rogers. 155 mm × 230 mm, pp. vii + 343, *illus.* Cambridge University Press, 1984. Price £35.00, US $67.50.

In recent years, satellite observations of the earth's atmosphere have formed a vital part of the data used in the routine production of surface and upper-air analyses, especially over the oceans and in the more remote regions of the world. In addition, data derived from satellites have increasingly proved of value as a research tool for the atmospheric physicist investigating the flow at upper levels, or the distribution of chemical species in the atmosphere. The appearance of this book on atmospheric sounding, which covers the whole field from instrument design to data-retrieval techniques, as well as

dealing with the applications of satellite data, will be welcomed by many operational meteorologists and research physicists alike.

The early sections of the book provide a general discussion of the goals of satellite remote sensing, along with a comprehensive review of the many operational and research spacecraft which have been launched to study the earth's atmosphere since Tiros 1 in 1960. Detailed descriptions of many of the visible and infra-red imaging instruments are given, as well as information on the microwave imagers which have been carried on a number of research satellites. The importance of satellite-borne instruments in providing measurements of elements of the earth's radiation budget is covered in Chapter 4 and results from a number of the experiments are presented, including the Earth Radiation Budget (ERB) experiment mounted on Nimbus 6 and 7.

The theory of remote temperature sounding, both tangentially at the atmosphere's limb and via the more conventional nadir view, is dealt with in considerable detail and the computation of instrument-weighting functions is described. Many of the sounding instruments themselves are illustrated and diagrams of their optical systems are provided along with the details of their weighting functions.

The chapter on retrieval theory deals with the derivation of temperature profiles and other meteorologically useful data from the radiances received at the satellite, and provides a very thorough coverage of the subject. In particular, the questions of uniqueness in the solution of the inversion process and the effects of noise are particularly well described.

The problems of interest to many operational meteorologists, such as the best ways to incorporate satellite data into numerical analysis schemes, are dealt with in Chapter 8, and various analysis schemes in use operationally at the moment are described. Further topics of operational interest that are covered are the problems associated with cloud clearing and the impact of satellite data on the quality of forecasts generated by atmospheric models.

Satellite data have also played a large part in extending our knowledge of the composition and dynamics of the upper atmosphere, and results from many of the experiments designed to explore these regions are presented, including the monitoring of stratospheric warmings via the Nimbus 4 Selective Chopper Radiometer (SCR) and the derivation of ozone profiles using data from the Limb Interferometer Monitor of the Stratosphere (LIMS) on Nimbus 7.

The final chapters of the book deal with the remote sounding of the atmospheres of other planets in the solar system and describe how the basic techniques of remote sounding have been adapted to provide us with new information on the composition and general atmospheric circulation of our neighbouring planets.

With such a rapidly developing subject, this book by three well-known workers in satellite observing provides a much-needed reference work which describes the status of many aspects of the subject and gives a large number of references to further literature. It will certainly find a place on the bookshelves of many researchers in the fields of satellite meteorology and the remote sounding of the atmospheres of other planets, with only the price deterring some people from buying their own copy until a paperback edition becomes available.

J. Turner

The climate of Europe: past, present and future, edited by Hermann Flohn and Roberto Fantechi. 165 mm × 245 mm, pp. x + 356, *illus.* D. Reidel Publishing Company, Dordrecht, 1984. Price Dfl 130, US $49.

The title of this book has a very familiar ring to it and is a little misleading inasmuch as a description of the present climate of Europe is not one of its main aims. The subtitle — Natural and man-induced climatic changes: a European perspective — is a more accurate description of its contents. It was

initiated by the Commission of the European Communities to accompany the European Climatology Research Programme and is a collaborative effort, being based on the contributions of eight specialists.

The book opens with a General Summary which is backed up by further summaries at the end of each chapter. These latter are of variable length and detail, however, and the busy reader is recommended to concentrate on the General Summary, which provides an excellent appraisal of the subject. After a brief introductory chapter, the main narrative begins with a description by Lamb of the changes which have taken place in European climate over the past thousand years. This is followed by a more detailed account by Schuurmans and Flohn of the instrumentally detected changes in the last hundred years or so. Chapter 4 is in many respects the core of the book and discusses Man's impact on climate (Berger). It properly concentrates on the effects of carbon dioxide and is accompanied by a description of the carbon cycle (Duplessy). Chapter 5 (Flohn, Dansgaard) examines some climates from the recent geological past for any clues they may provide to the future behaviour of the climatic system. The section concludes with an examination of the consequences of a glaciated Antarctic continent being accompanied by an ice-free Arctic Ocean. The final chapter (Bourke, Rosini) considers the impact of climatic changes on European agriculture.

Somewhat surprisingly, the weakest part of the book lies in its incomplete account of the physical basis of climate and climatic change. Most of the physical explanations are offered in Chapter 4, but they are all very brief. The account of the greenhouse effect is poor and the role of the oceans is not fully discussed. In the General Summary, for instance, two vulnerable aspects of the climatic system are identified — the extent of polar sea ice and coastal and equatorial upwelling. The possible importance of the latter is emphasized in the discussion of the consequences of one pole being glaciated while the other is ice free. Yet nowhere in the book is there a discussion of the importance of marine life for atmospheric CO_2 levels, or of the Southern Oscillation and El Niño. This contrasts with the very full coverage given to the polar ice, although even here some space could have been devoted to plans for the diversion of Soviet rivers (they are briefly mentioned under the effects of changes in land use). Reasonably enough, minority views are not represented and sunspots are dismissed in a single paragraph in Chapter 1. The uncertainty over the role of volcanic dust, however, is not mentioned; it is presumed to cause surface cooling, and in Chapter 5 is held to be largely responsible for the 'Little Ice Age'.

The discussion of recent climatic changes in Chapter 3 is too long. There is too much presentation of raw data and the reader is showered with statistics and references. It might have been better to have extended Lamb's account of the last thousand years and to have used the extra space for a chapter on the physical basis of climate and climatic change (the present introductory chapter is too short to accomplish this).

There is a fair sprinkling of typographical errors and some of the diagrams lack clarity. There is a good index and many references, although those to papers in journals do not contain the titles of the works.

Despite these criticisms, the book has much to commend it. The main shortcomings mentioned above can probably be ascribed to insufficient collaboration arising out of its combined authorship. Yet it would have been impossible for a single person to have written this book and it is clear that a large amount of editorial and collaborative effort has gone into the work. This has seen its reward in a volume with a well-conceived plan and an impressive unity of style. Each chapter stands on its own and there are extensive cross-references. The scope of the book is especially good. Despite the many publications in this field, it does occupy a niche which is not covered by others, although inevitably it overlaps with many. The General Summary and Chapters 2 and 5 are all excellent and could hardly be improved upon. The volume can certainly be recommended as a readable and well-balanced introduction to the subject of climatic change, even if the reader will need to look elsewhere for further accounts of the greenhouse effect and the roles of the oceans and volcanic dust.

R. C. Tabony

Books received

The listing of books under this heading does not preclude a review in the Meteorological Magazine at a later date.

Atmospheric electrodynamics, by Hans Volland (Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1984. DM98, US$35.70) brings together two subjects usually treated separately: low-frequency electromagnetic fields of lower atmospheric origin and those of upper atmospheric origin. The first, known as geoelectricity, deals with thunderstorm phenomena and related problems such as the global electric circuit, lightning and atmospherics. The second subject is associated with ionospheric and magnetospheric electric fields and currents: dynamo currents, Birkeland currents geomagnetic pulsations and the like. Originally considered as part of geomagnetism, this is now a subfield of magnetospheric physics. The book stresses the interconnection between the two and presents to workers in different fields (meteorology, aeronomy, space physics) a unifying view of today's knowledge of lower and upper atmospheric electromagnetic fields and currents at low frequencies (periods larger than 10^{-5} s).

Prophet – or professor? The life and work of Lewis Fry Richardson, by Oliver M. Ashford (Bristol and Boston, Adam Hilger Ltd, 1984. £18.00, US $29.00) is the first full-length biography of Lewis Fry Richardson to be published and contains much material not previously available to the public. It is a timely reappraisal of his life and work, and one that will reach a wide audience. Throughout, no prior familiarity with Richardson's work is assumed, and the more technical aspects of his ideas are kept to a minimum. Nevertheless, for those stimulated by Richardson's ideas, there are extensive references to his published work, as well as to archival material concerning other aspects of his life.

Engineering hydrology (3rd edition) by E. M. Wilson (London and Basingstoke, Macmillan Press Ltd, 1983. £16.00, £7.95 (paperback)) is a new, thoroughly revised and completely reset edition. Some of the findings of the Flood Studies Report (FSR) carried out by the Institute of Hydrology in 1975 have been incorporated. The opportunity has also been taken to expand the sections on flow duration curves and the rainfall data of the British Isles, through use of the Meteorological Office's contribution to the FSR. Finally, the references have been updated and the selection of problems widened.

Honour

We are pleased to record that Mr H. D. Chillingworth, the rainfall observer at Bradwell-on-Sea, Essex was awarded the British Empire Medal in the New Year's Honours List. Mr Chillingworth began making daily observations in 1926, following on from his father whose first observations were made in 1883.

THE METEOROLOGICAL MAGAZINE

No. 1352 March 1985 Vol. 114

CONTENTS

NOTICE

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

Applications for postal subscriptions should be made to HMSO, PO Box 276, London SW8 5DT.

Complete volumes of 'Meteorological Magazine' beginning with Volume 54 are now available in microfilm form from University Microfilms International, 18 Bedford Row, London WC1R 4EJ, England.

Full-size reprints of Vols 1–75 (1866–1940) are obtainable from Johnson Reprint Co. Ltd, 24–28 Oval Road, London NW1 7DX, England.

Please write to Kraus Microfiche, Rte 100, Millwood, NY 10546, USA, for information concerning microfiche issues.

HMSO Subscription enquiries 01 211 8667.

Printed in England for HMSO and published by
HER MAJESTY'S STATIONERY OFFICE

£2.30 monthly

Dd. 737126 C13 3/85

Annual subscription £27.00 including postage

ISBN 0 11 727557 3
ISSN 0026–1149